Performance of the BNL Magnetron H- Source

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Description of source

Source operating experience

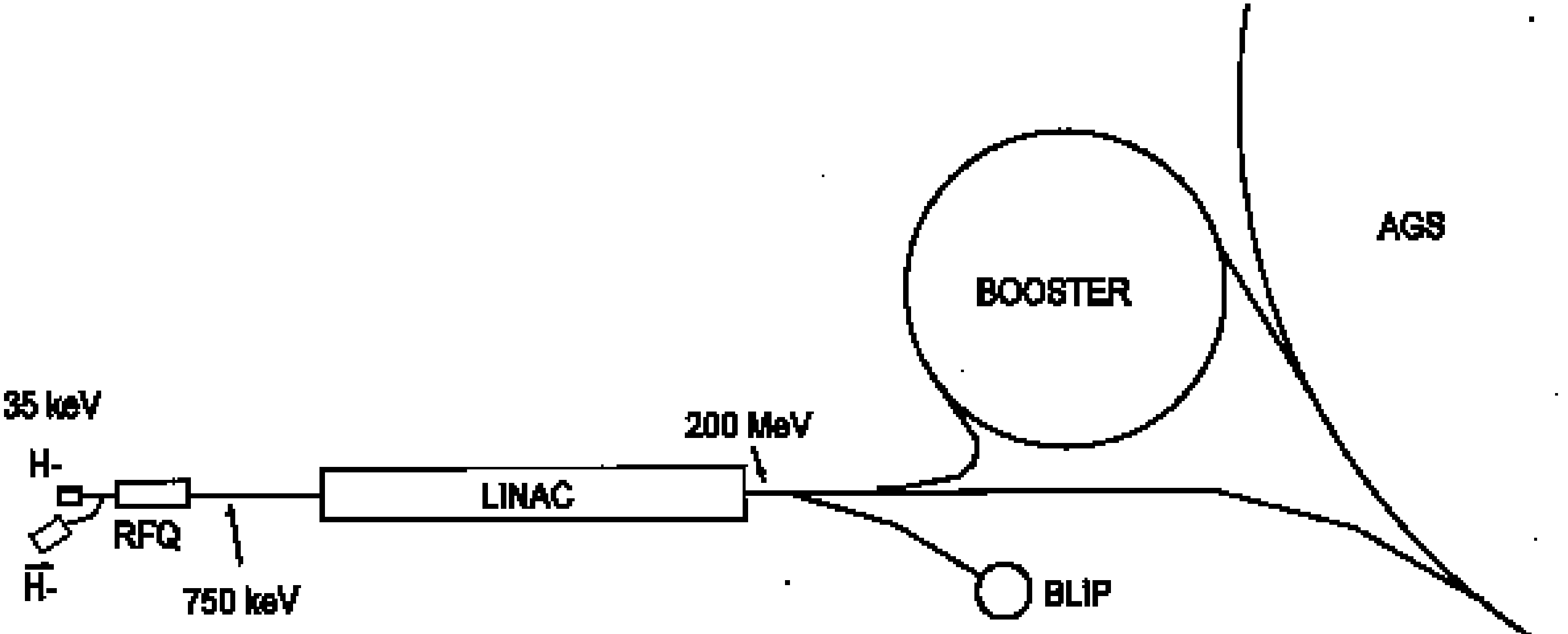
Performance on Linac

(Fast chopping)

General Linac Parameters

- H-
- Energy = 200 MeV
- Current = 35 mA
- 500 μs, 7.5 Hz
- 100-150 μA average current (for BLIP)
- Polarized H- : 500 μA, 75% Polarization

General Layout



History of Magnetron at BNL

Magnetron surface plasma source (similar to FNAL)

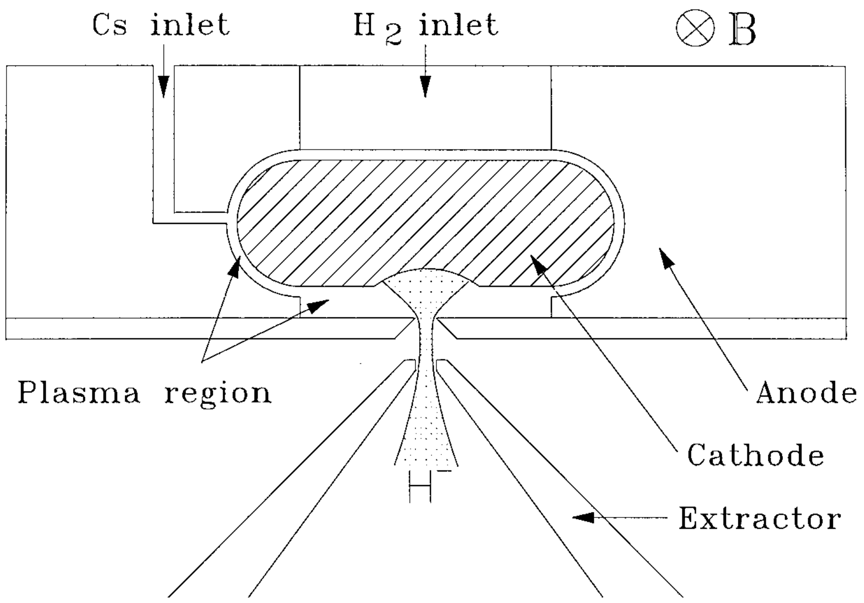
1982 - Switched to H- injection at BNL. Source installed in dome of 750 keV Cockcroft-Walton preinjector, slit extraction geometry.

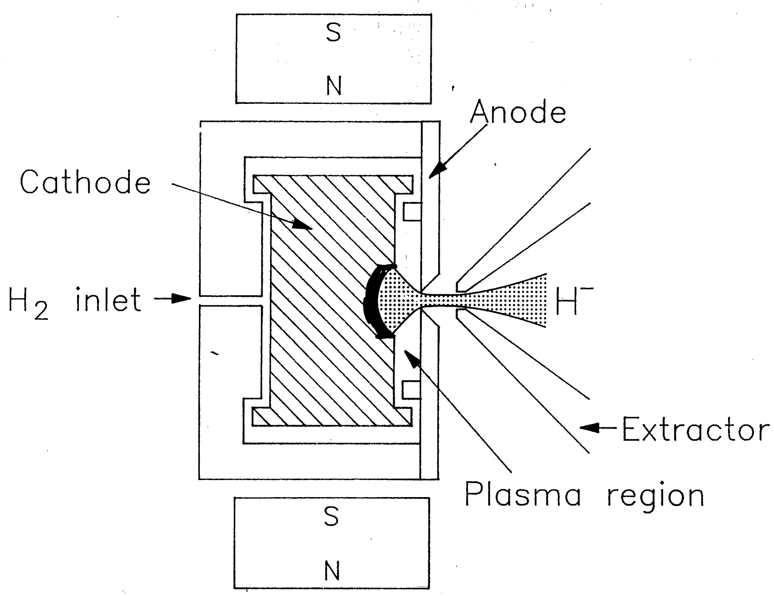
1989 - Installed RFQ preinjector. Converted to circular aperture.

	H- (mA)	**Arc I (A)**	**Arc V (V)**	**Arc Effic (mA/A)**	**Pwr Effic (mA/kW)**
Flat cathode	50	150	150	0.3	2.2
Grooved	50	50	150	1	6.7
Circular	100	10	150	**10**	**67**

The good power efficiency of the magnetron in the present geometry leads to a very high reliability.

Magnetron Source





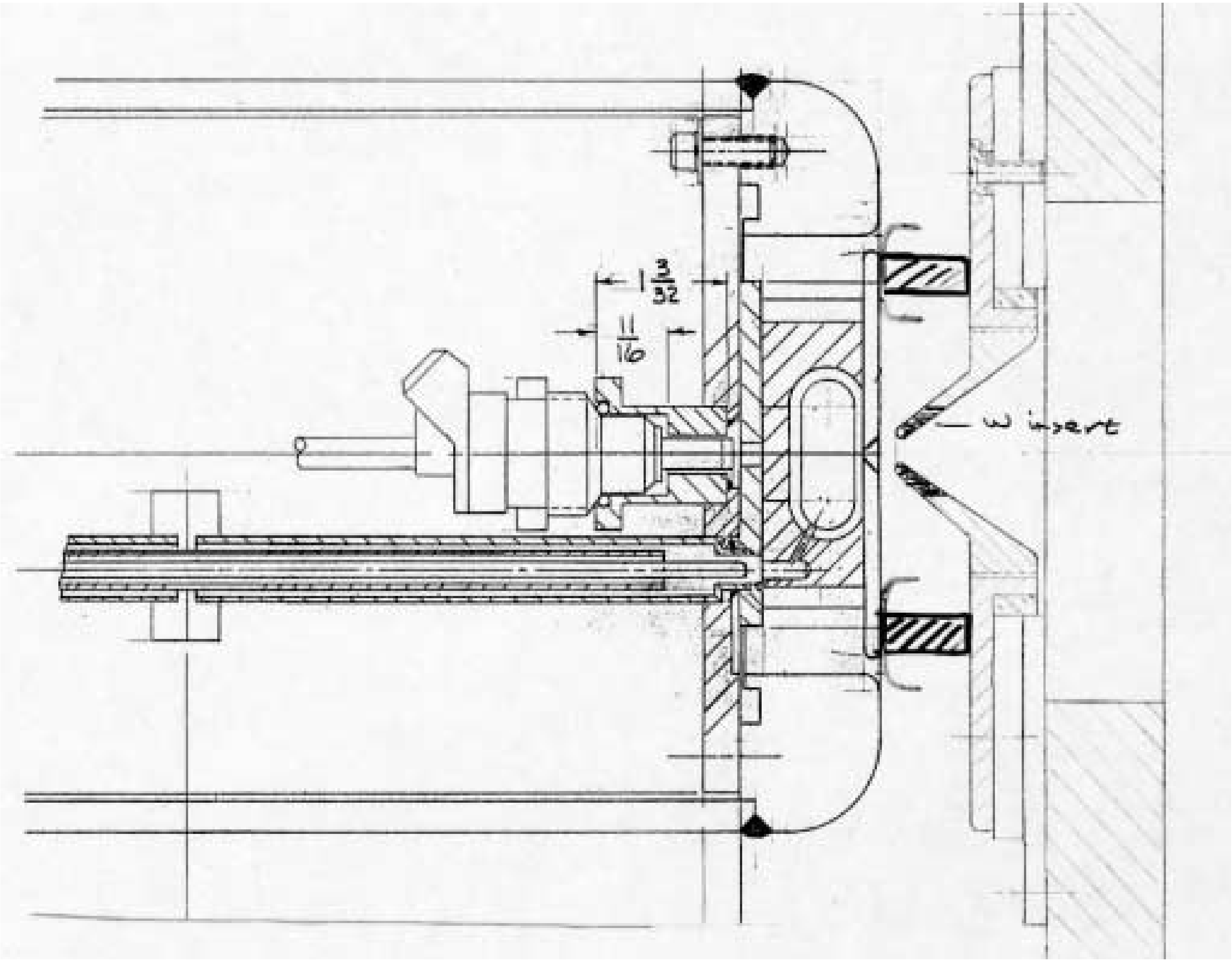
Typical Running Parameters

H- current	90 - 100 mA (1.5 A/cm^2)
Extraction	35 kV
e/H	0.5 - 1.0
Arc voltage	140-160 V
Arc current	8-18 A (often run 15-18 A to keep source temp up)
Rep rate	7.5 Hz
Pulse width	700 μs
Duty factor	0.5%
RMS emittance	~ 0.4 π mm mrad (normalized)
Cs consumption	< 0.5 mg/hr (T_{Cs} = 90 - 100 C; 5 g lasts >6-9 months)
Gas flow	~ 2.5 x 10^{-2} T-l/s (2 sccm)

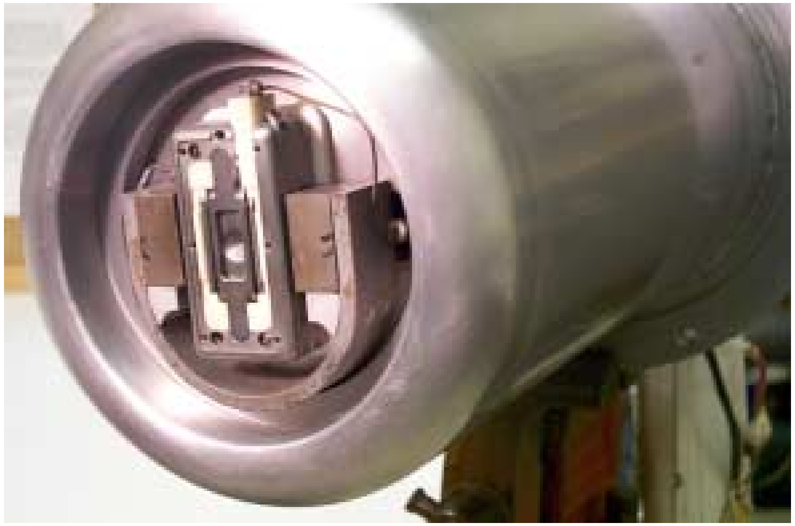
Times between source maintenance are approximately 6 months continuous (3-9 months; almost always shutting down when program ends, rather than due to failure).

We can shut the source down, change it out, restart, and be running well again in 8 hours.

Ion Source

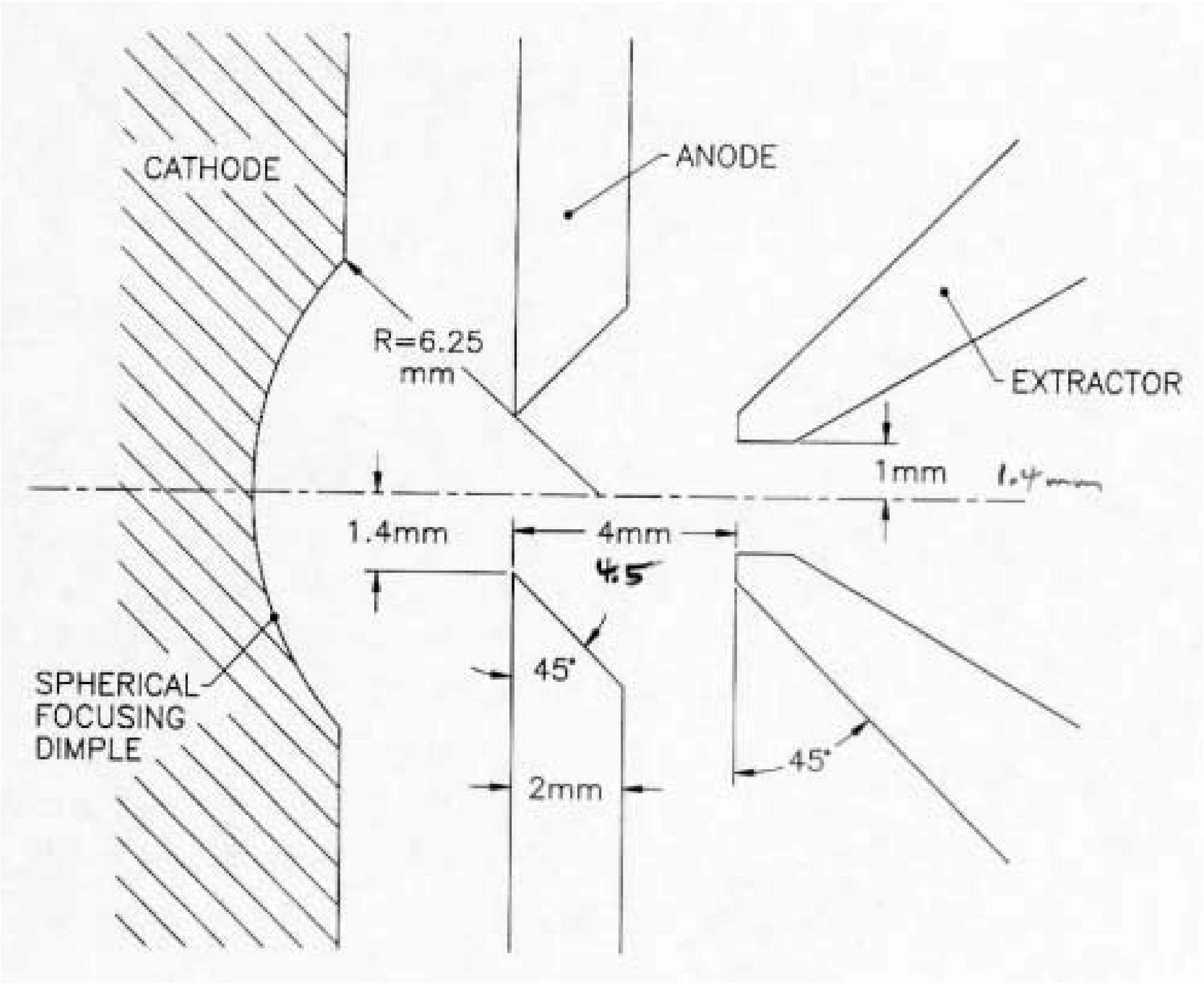


Source Assembly Stages

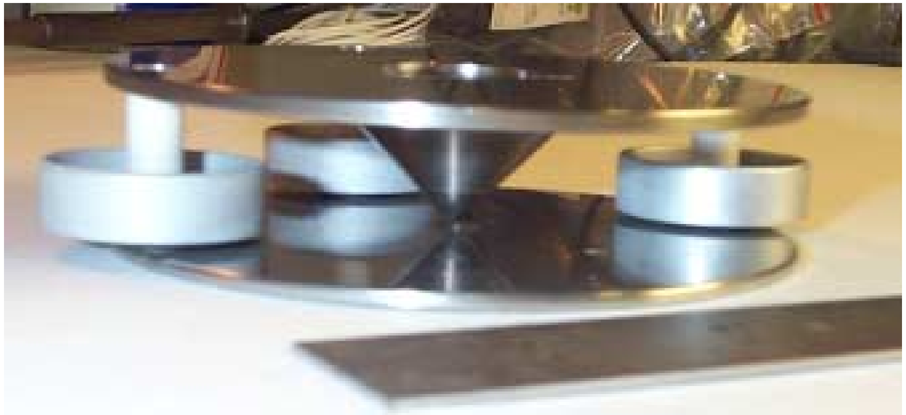



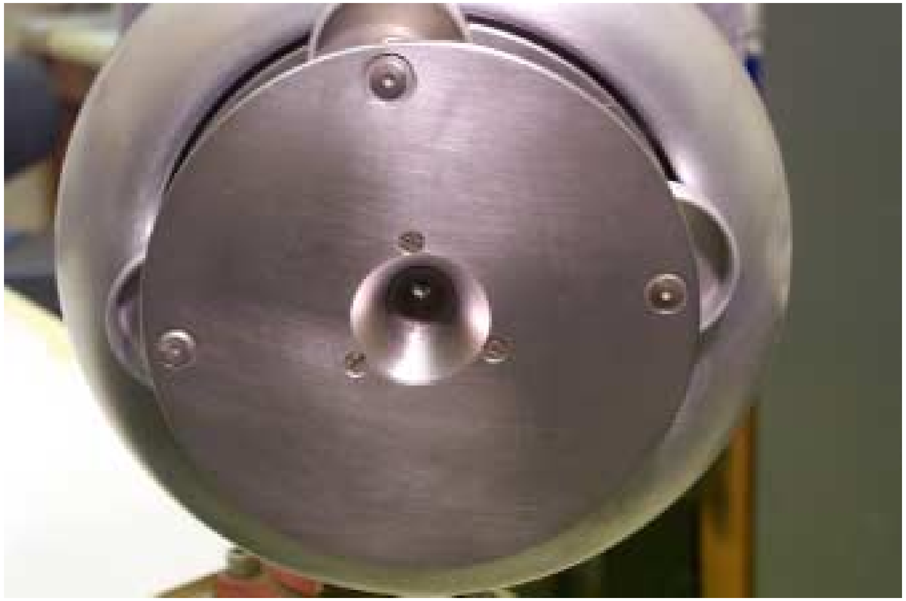
Source in Vacuum Box

Ion Source Extraction

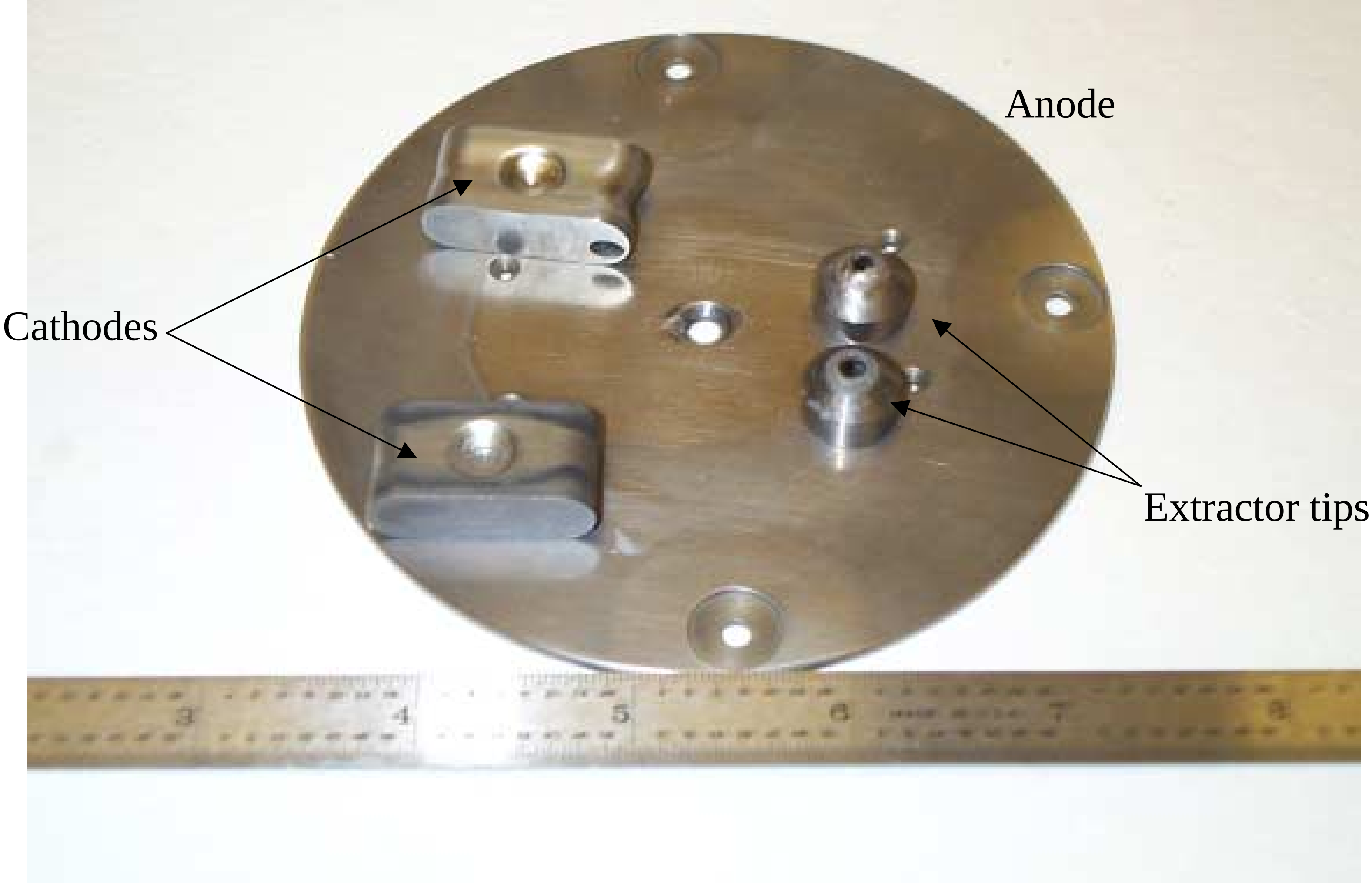


Extractor Assembly

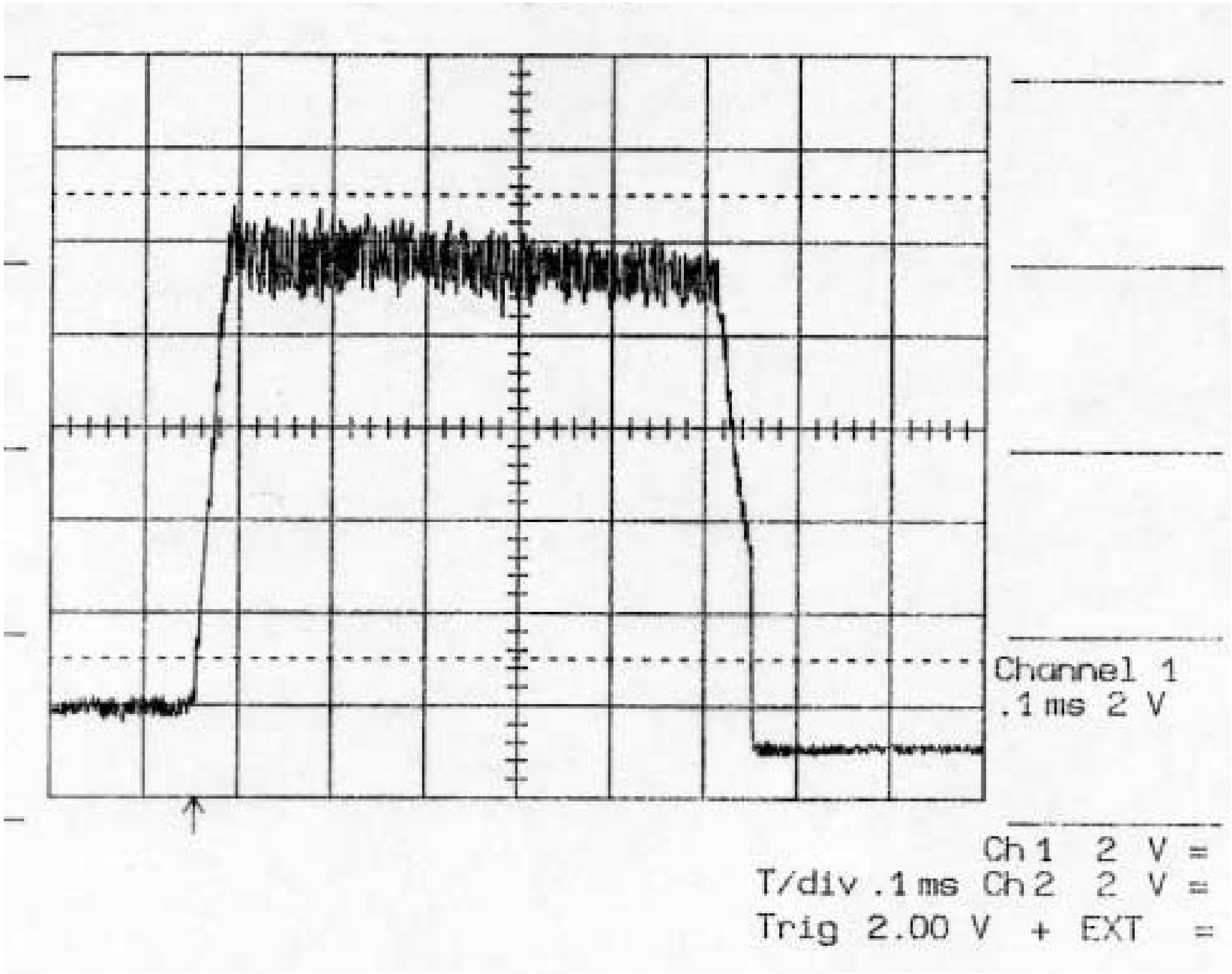




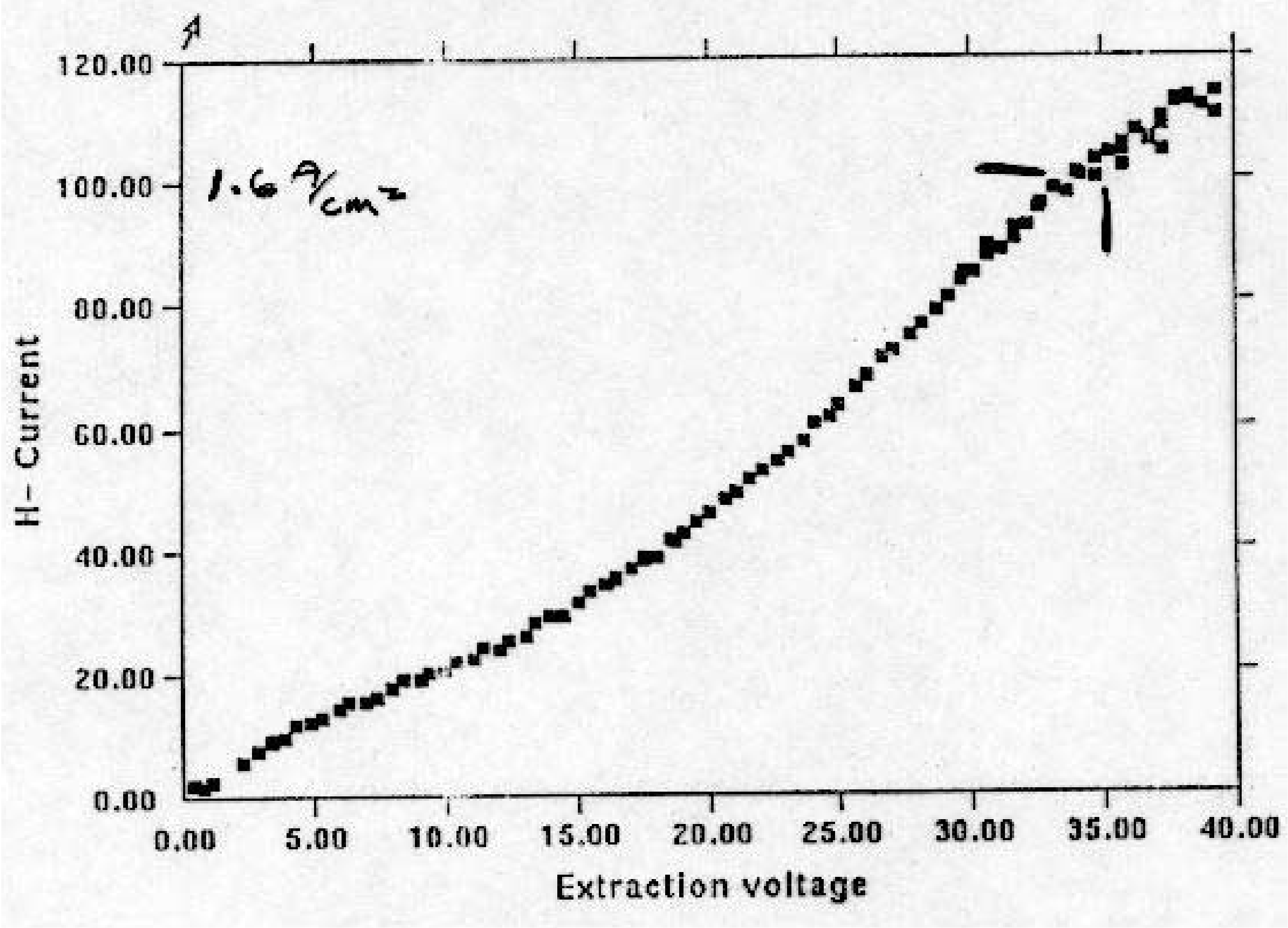
Used Source Parts



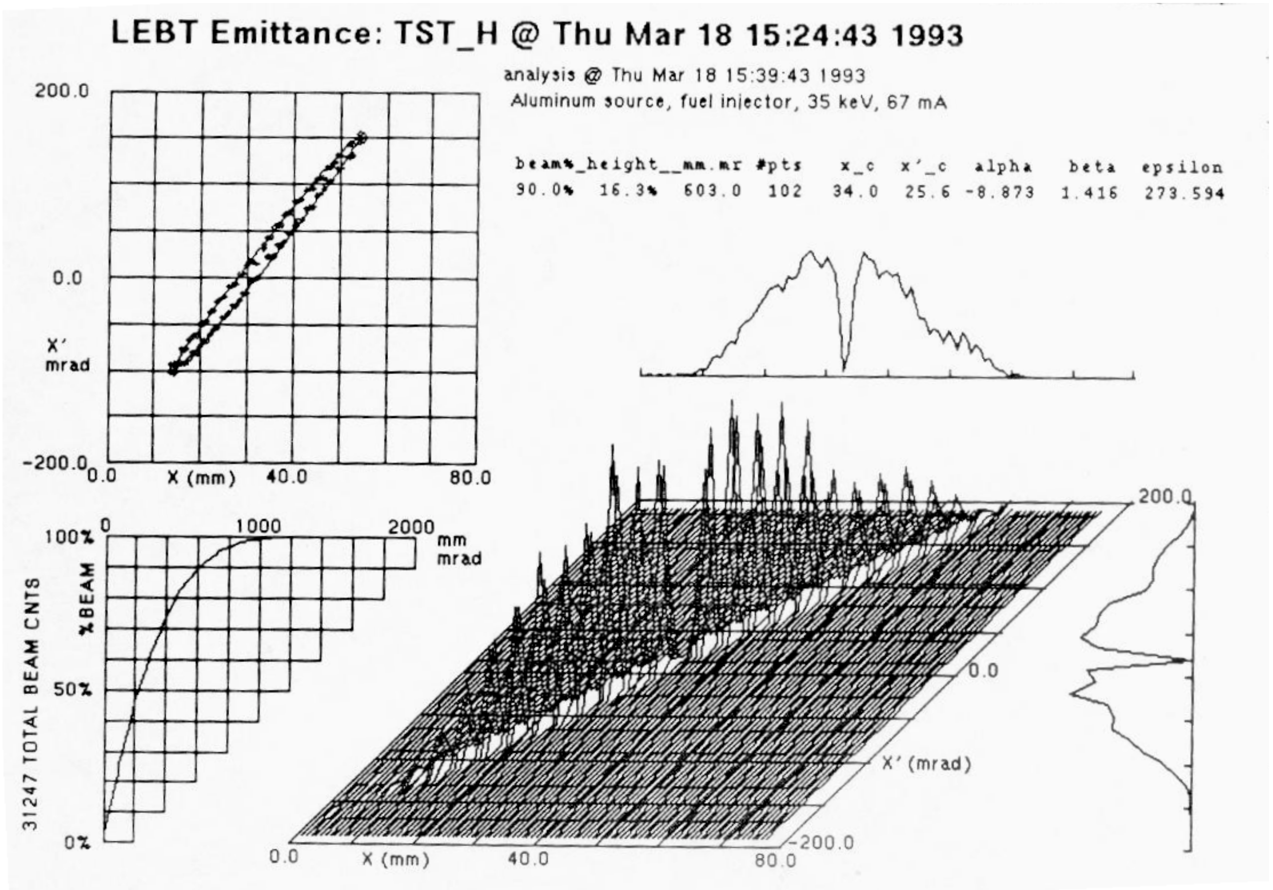
Ion Source Output
(20 mA/div)



Current vs Extraction Voltage



Example of Ion Source Emittance



ε (n, rms) ~ 0.4 π mm mrad

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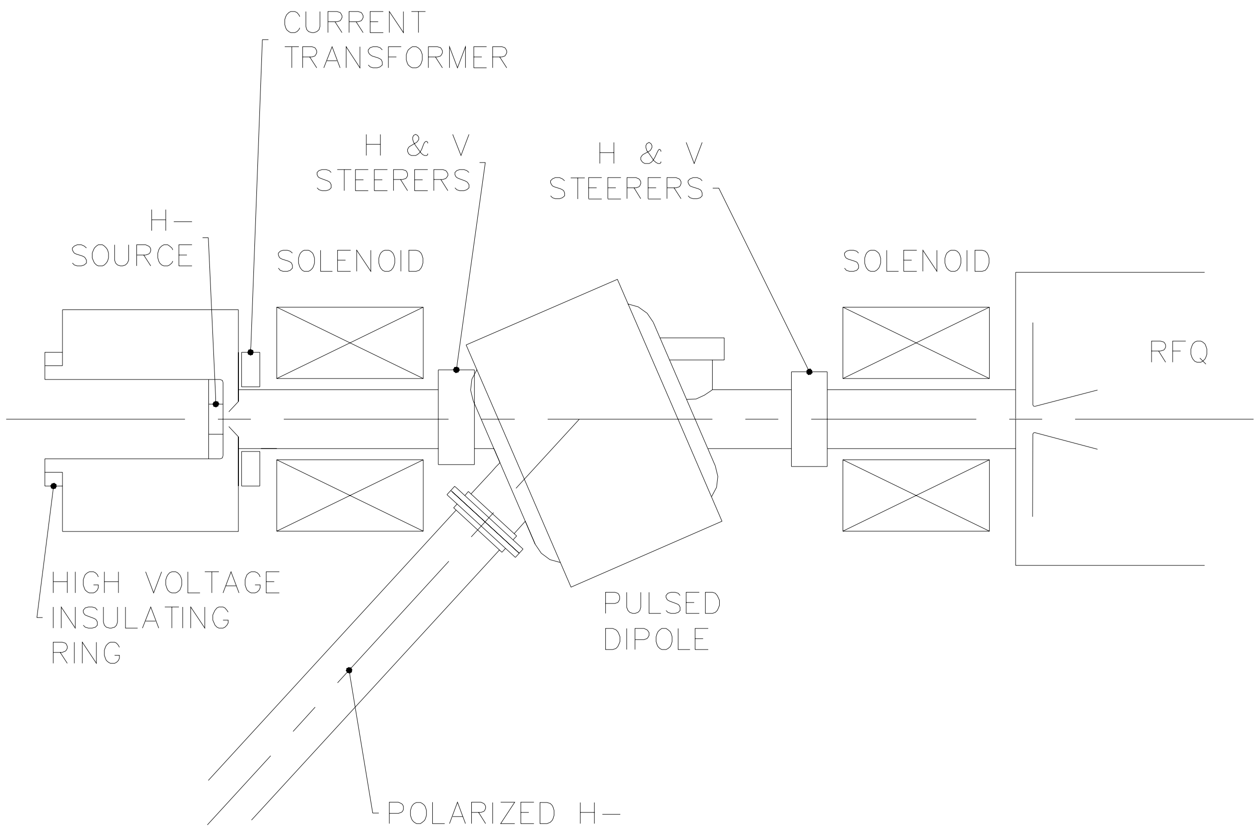
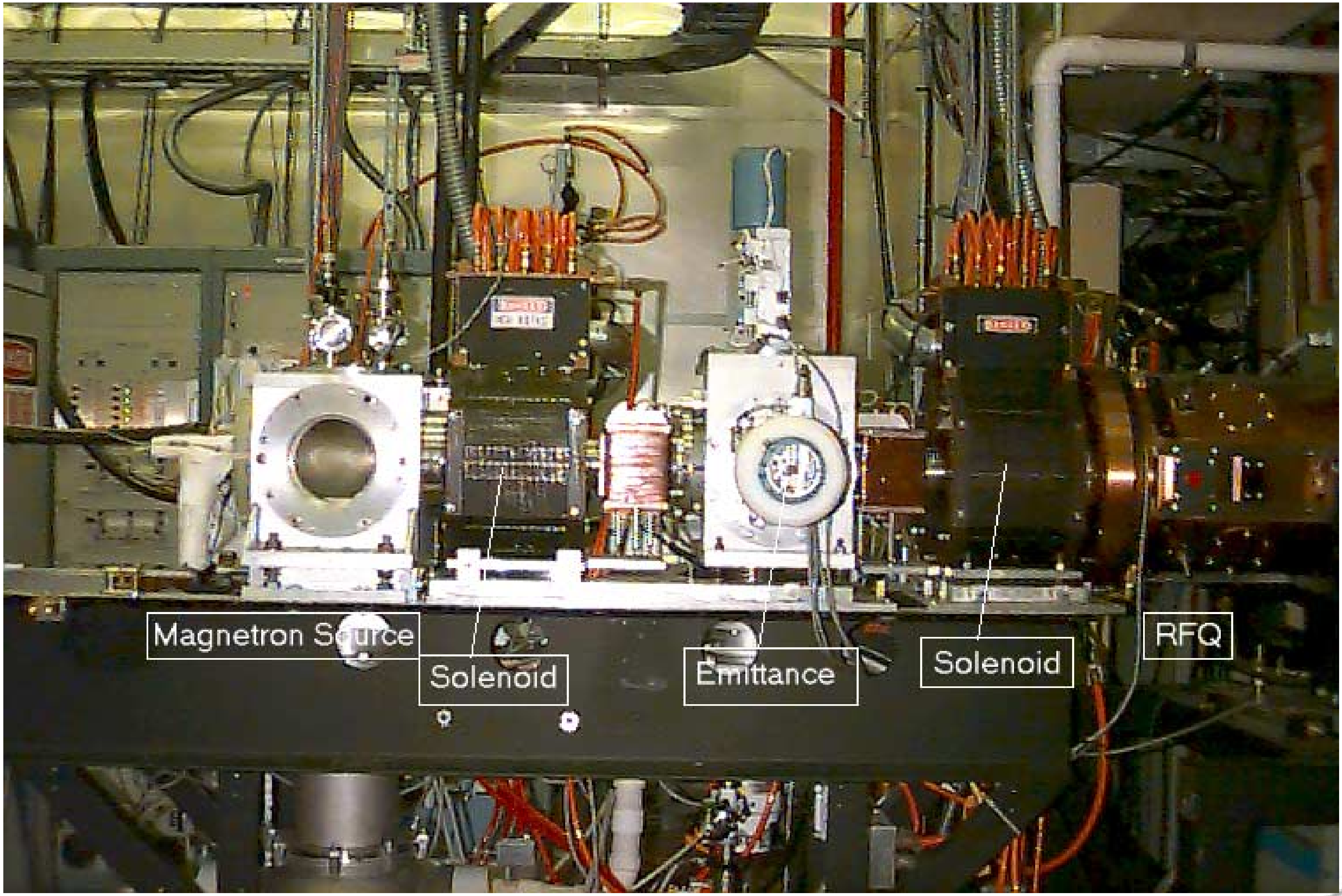
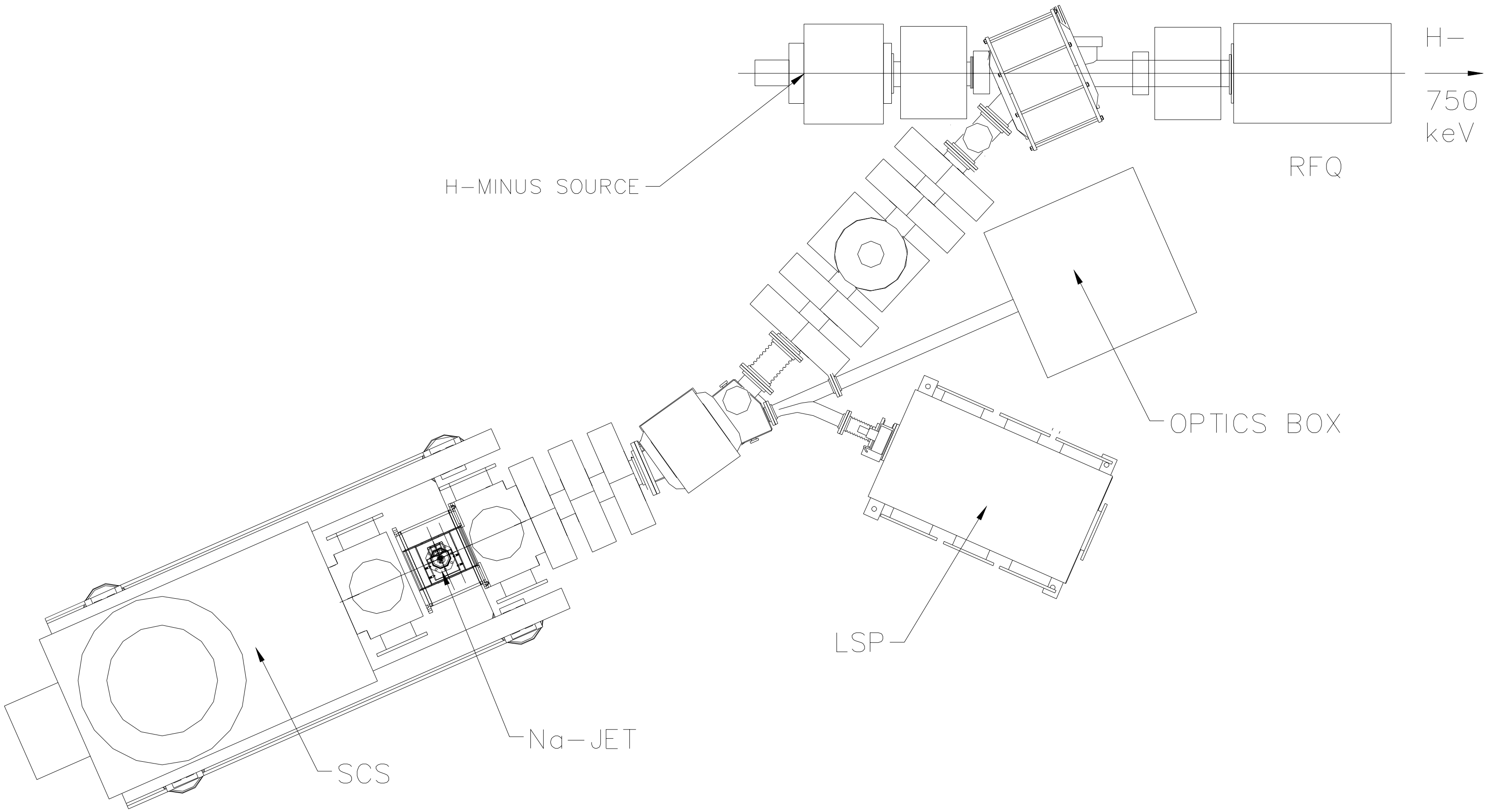
LEBT Layout


CURRENT
TRANSFORMER
H & V
STEERERS
H & V
STEERERS
H−
SOURCE
SOLENOID
SOLENOID
RFQ
HIGH VOLTAGE
INSULATING
RING
PULSED
DIPOLE
POLARIZED H−

35 keV LEBT (before OPPIS)



LEBT with polarized H^-



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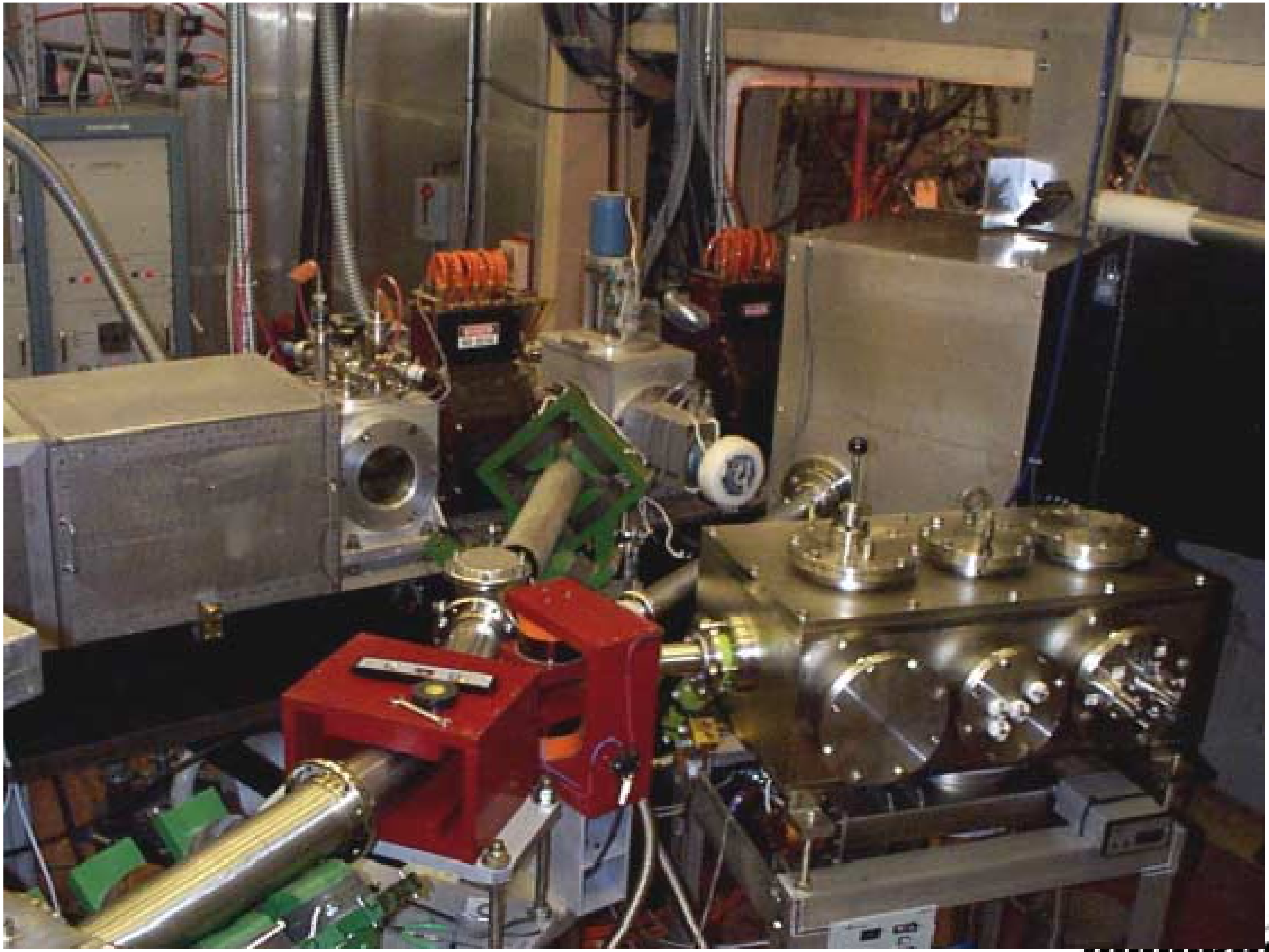
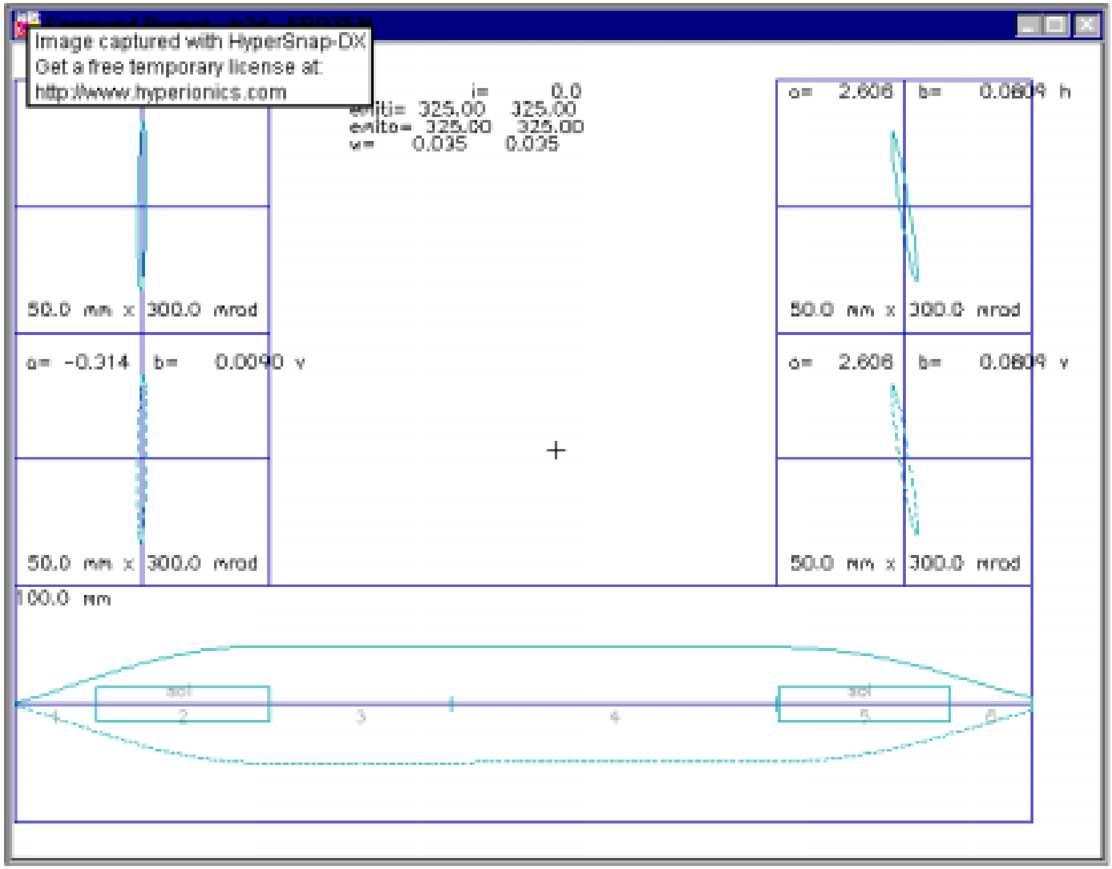
LEBT with OPPIS

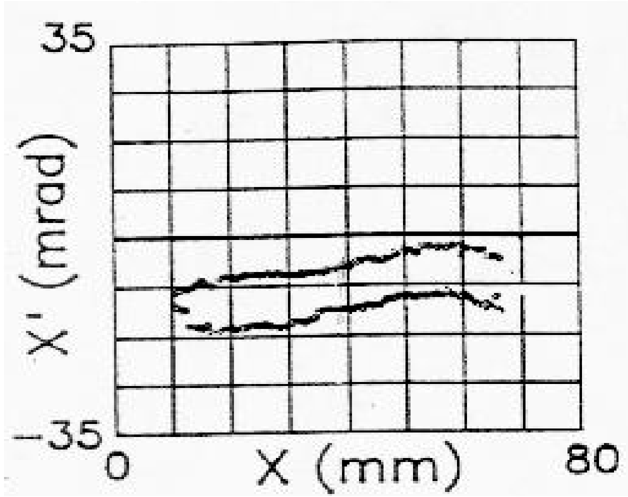


LEBT

- 1.4 meters long, 2 solenoids, pulsed (2.5 kG)



Middle of LEBT
(after 1 solenoid)



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Comments

The source has a very small discharge volume (~ 1 cm^3), so good gas pulsing is effective.

We typically operate the source slightly gas- and Cs-starved, which keeps it reliable, but makes the discharge (and beam current) noisier.

By operating with space-charge limited extraction, and “flooding” the transport line, the transmission values suffer, but the current out of linac is high and stable.

During a long run:

Once the source is started, we try to keep it running. That is, even for a 1-2 week linac shutdown, we will leave the source pulsing, with the extractor on. The source will almost always recover fine from a shutdown (ex. power outage), but it is easier to just keep it on. (On the test bench, a source may be turned on and off daily without problems).

We try to keep the extraction voltage on whenever the source is running. Beam heating of the extractor tip keeps it clean. If the extractor is turned off for a couple hours, it may have to be reconditioned up in voltage.

Adjusting the gas flow occasionally (every couple weeks) is about all that anyone has to do. It's not unusual for the source to run for a month at stable current without a single adjustment.

Typical observations following a long run:

The source is very clean inside (polished)

There is erosion of the extraction tip (ions, electrons), anode aperture (electrons), cathode dimple (backstreaming ions), cathode opposite Cs feed (discharge). In spite of these very significant changes in dimensions for the extraction geometry and cathode focusing, the performance remains very constant (output from linac). We often clean parts and reinstall, even with the heavy erosion.

Over long runs, we sometimes see that we have have to increase the gas to the source periodically. When we open up, there is a soft solid whitish material obstructing the gas inlet. Once exposed to air, it slowly takes in moisture and becomes liquid. (**CsOH**).

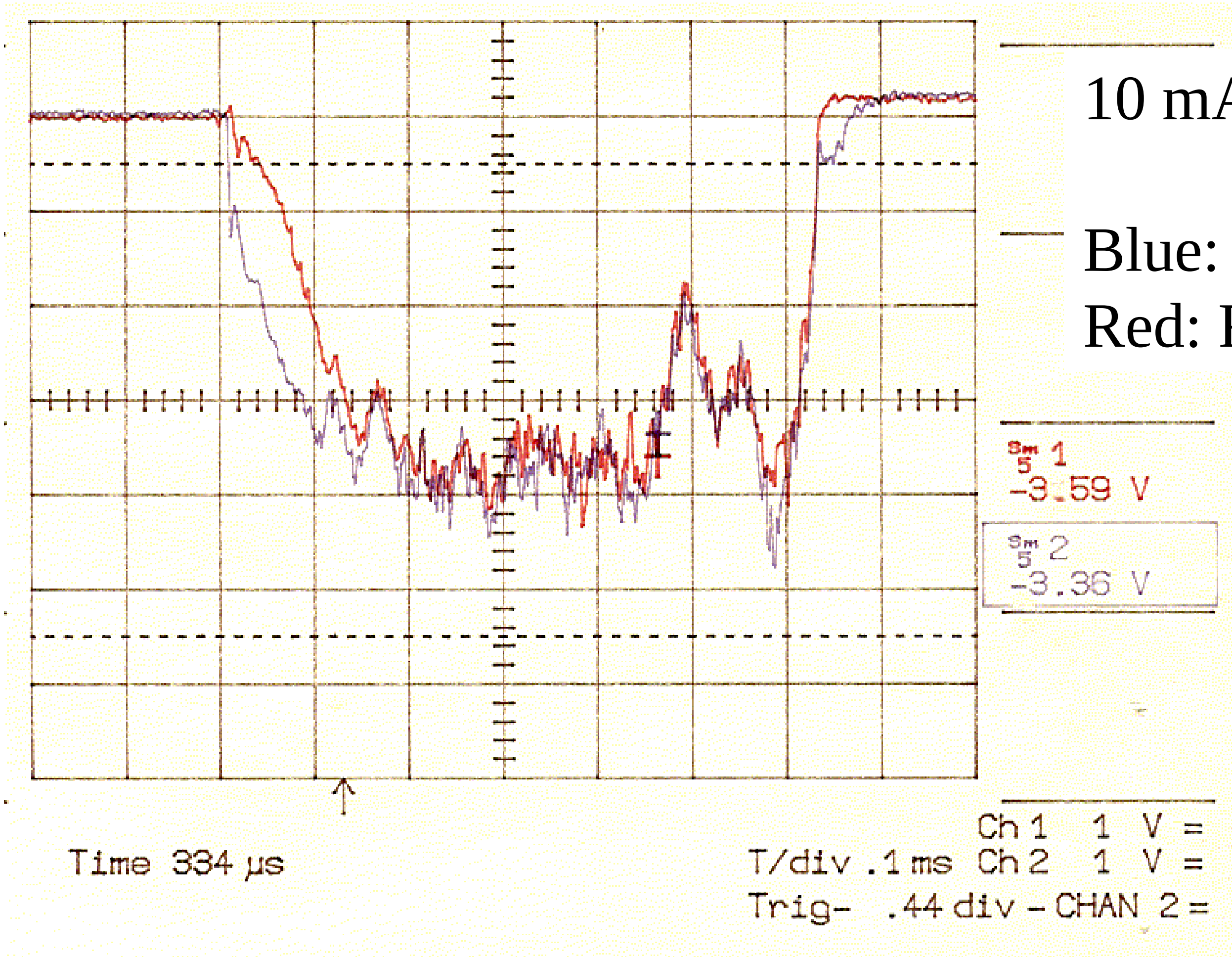
Cs is not seen beyond the extractor electrode.

RFQ

- Built by LBL (1989)
- 35 keV $\rightarrow$ 750 keV; 200 MHz
- 1.6 meters,146 cells, P=121+35 kW, 1.48Kp, Vane Voltage 67.2 kV,Q=6644
- Transmission (80-90%)
- Runs extremely reliably - no downtime in 13 years

RFQ Transmission

(Not typical. This is at reduced current, and with fluctuations in the discharge, just as an illustration of how good the transmission can be).



10 mA/div

Blue: RFQ input
Red: RFQ output

Emittances measured in and out of the RFQ

(I ~ 40 mA)

35 keV

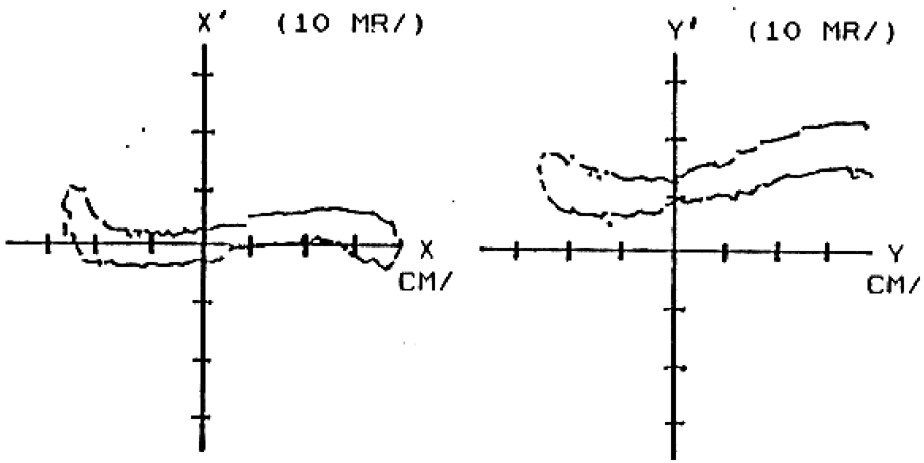


Fig. 4 Emittances measured in the 35 keV transport section. $\varepsilon_n(90\%) \approx 0.11$ π-cm-mrad in both planes.

750 keV

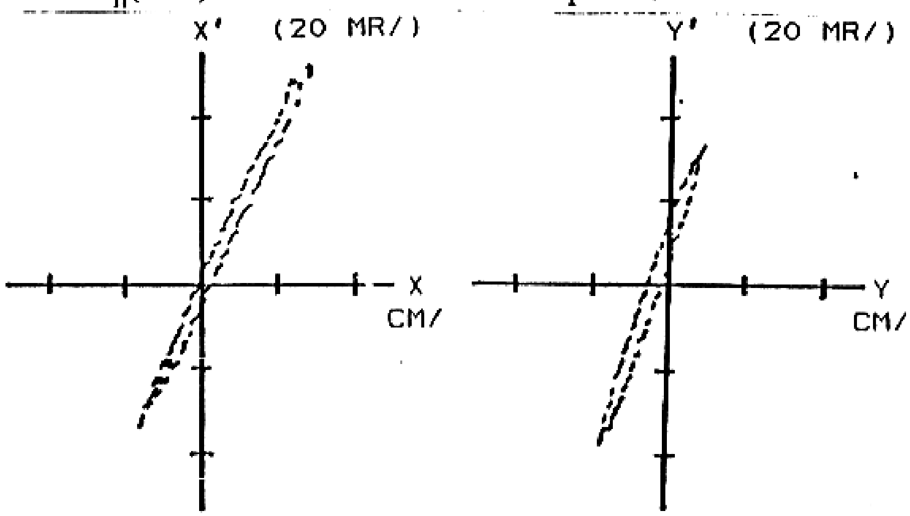
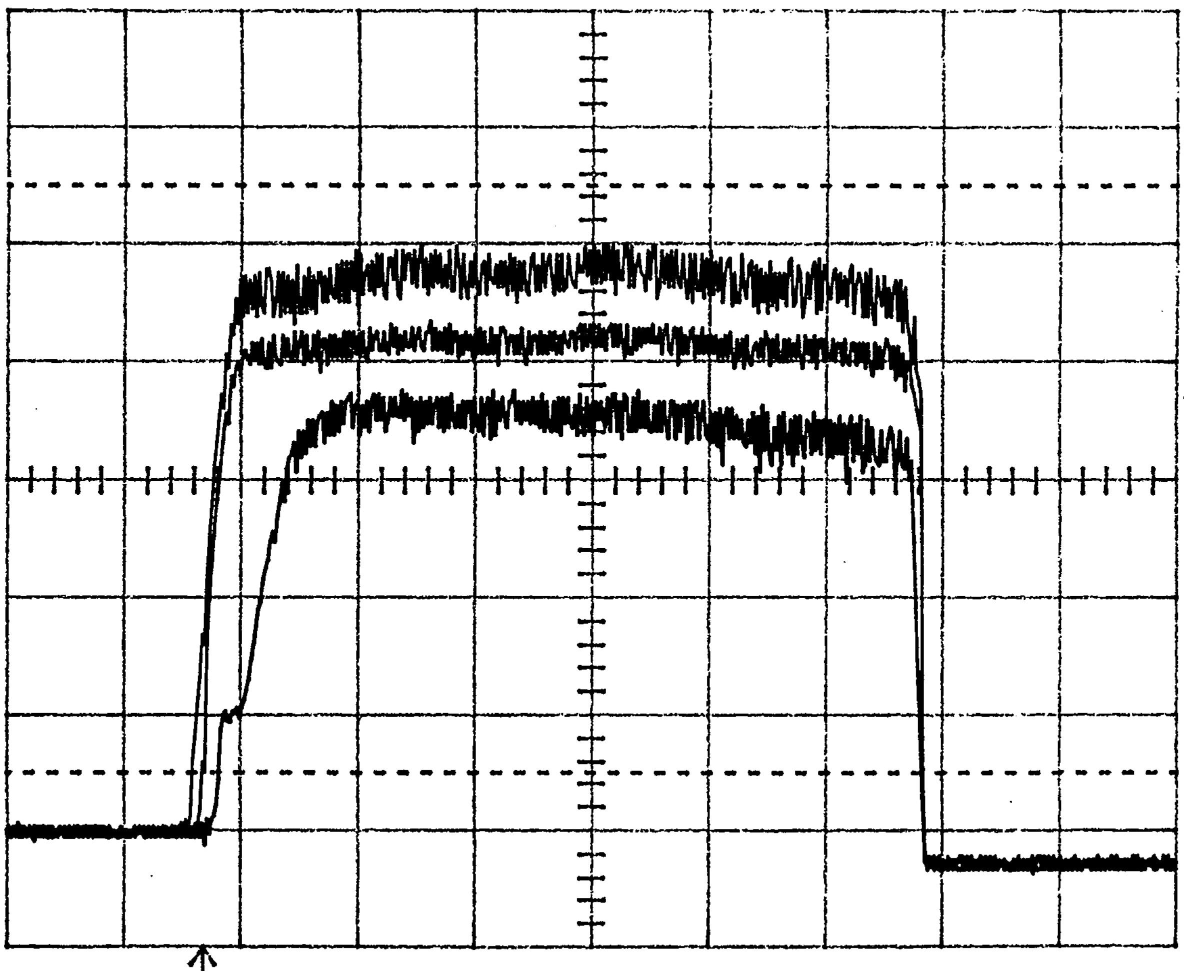


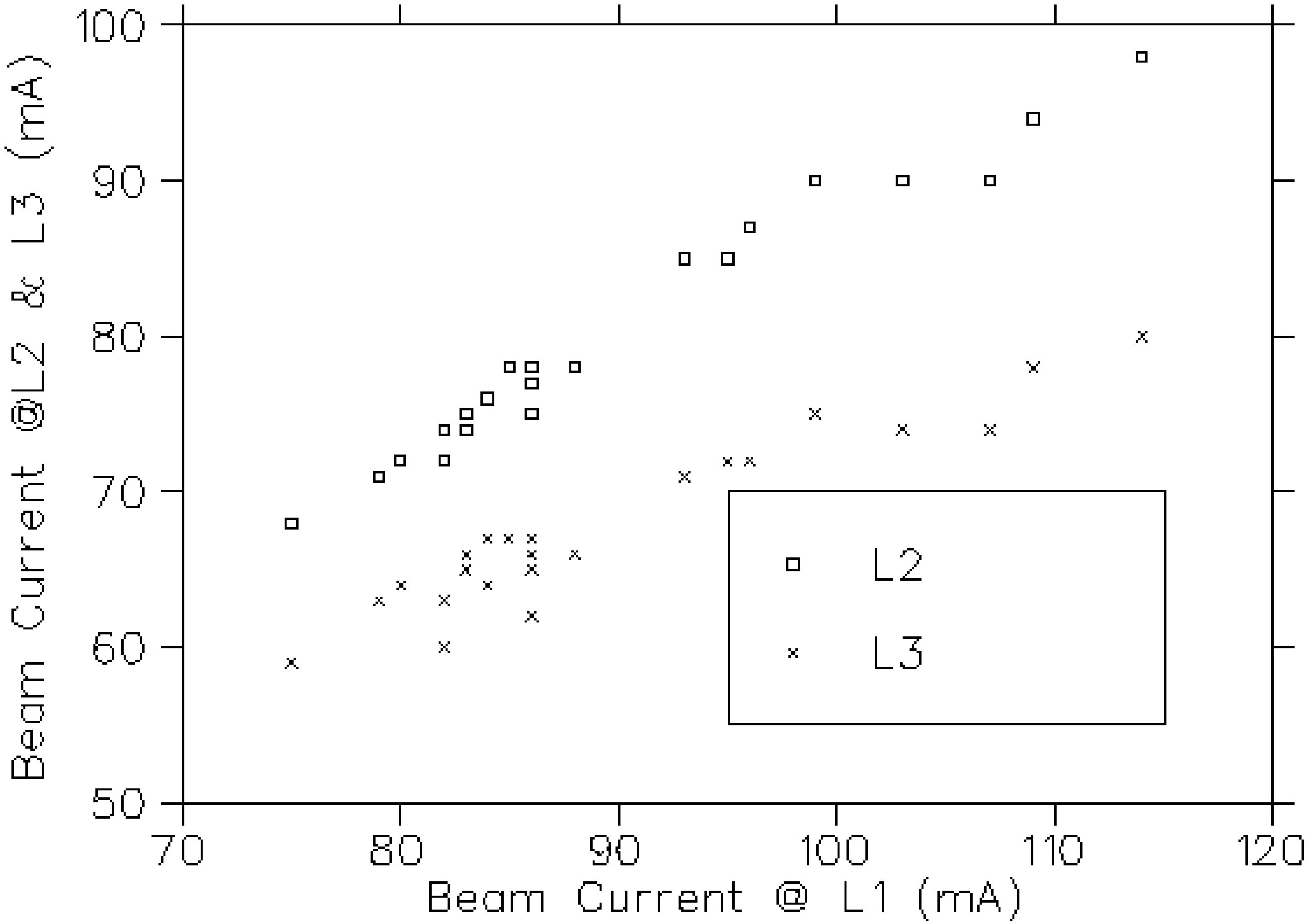
Fig. 5 Emittances measured 23 cm from the RFQ exit. $\varepsilon_n(90\%) \approx 0.12$ π-cm-mrad in both planes.

Source output, RFQ input, RFQ output (20 mA/div, 100 μS/div)



This represents our typical operation, where we run with non-optimized extraction.

Current in & out of RFQ



L1: source L2: RFQ in L3: RFQ out

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BNL Magnetron Source / RFQ

Performance ~ 1989; extraction optimized, reduced current:

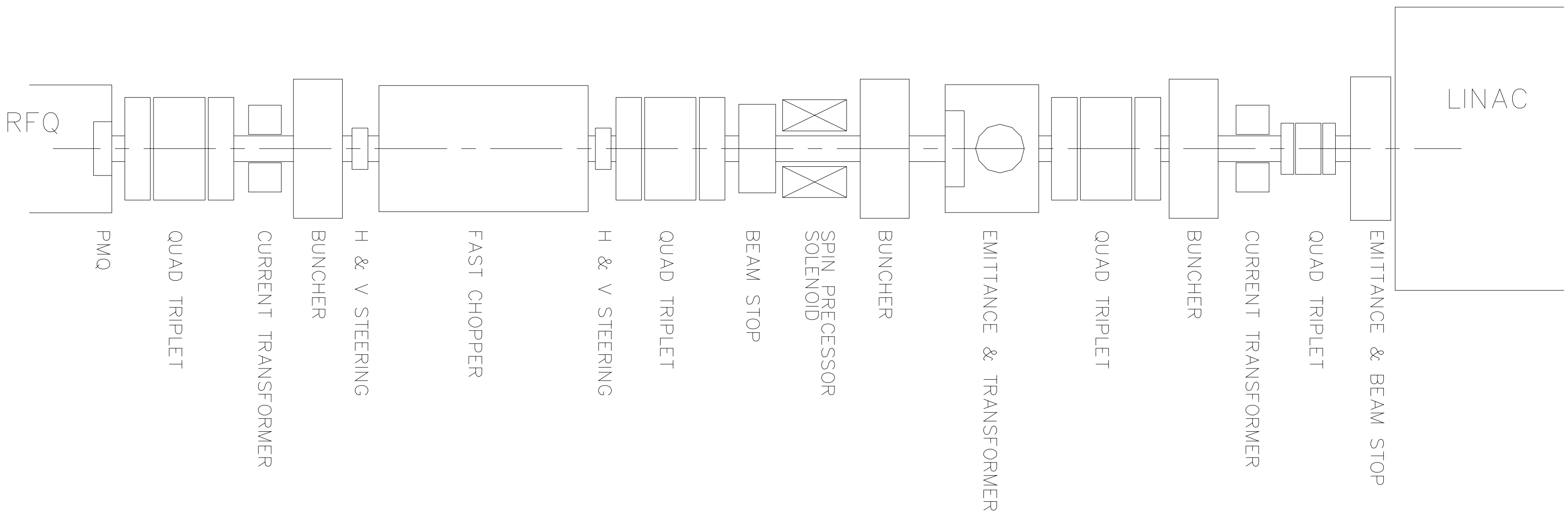
40 mA in and out of RFQ ("100%" transmission)
ε(norm, rms) ~ 0.3 π mm mrad (in and out of RFQ)
(< 10% emittance growth through RFQ)

As the source ran for months, the current out of the source and linac would grow, as anode and extraction apertures opened up from erosion. We eventually started making the parts with the increased apertures, which resulted in poorer transmission numbers, but good, stable running.

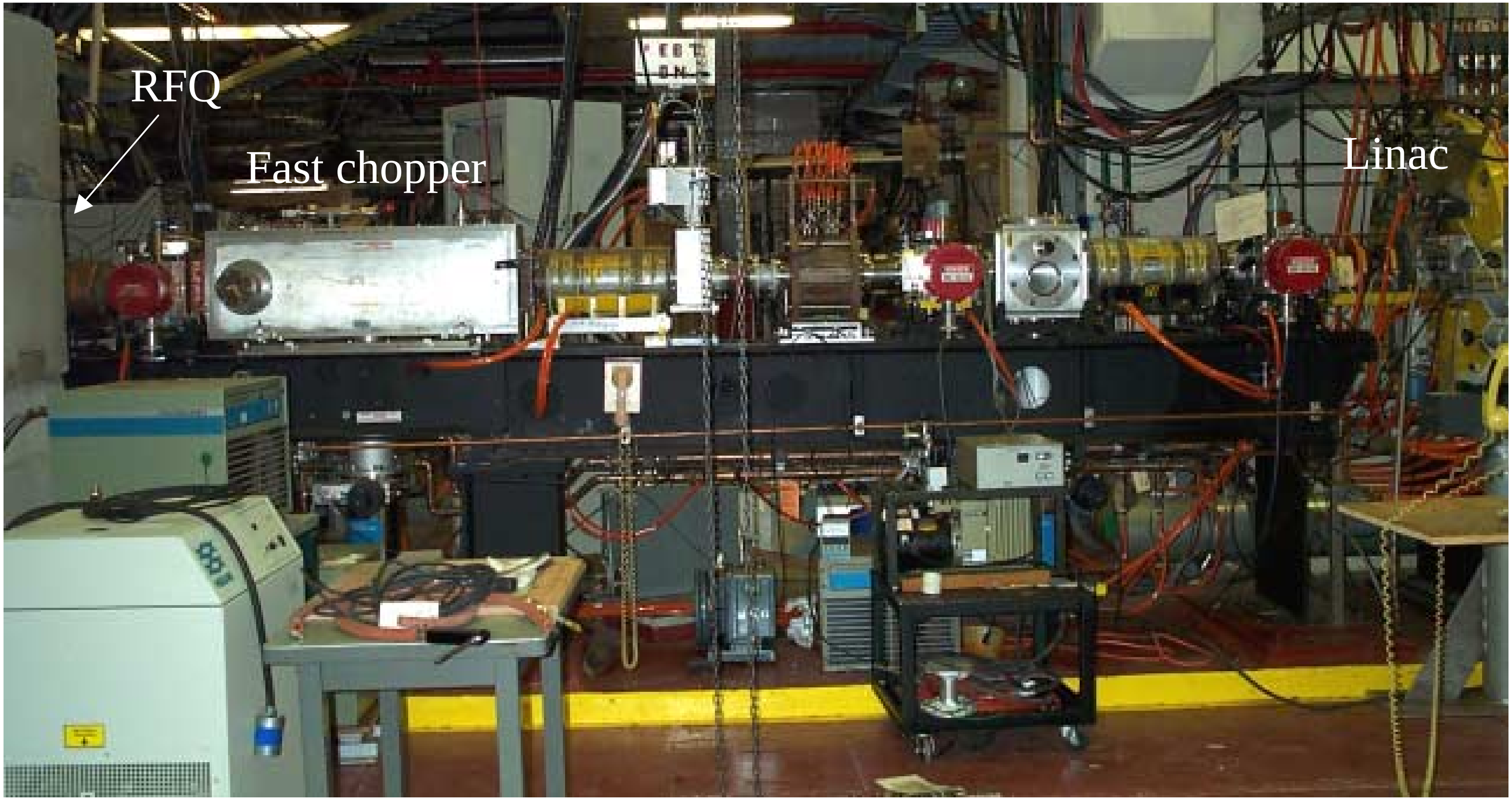
Performance from ~ mid-90's; operational

80 mA at the RFQ input
ε(norm, rms) ~ 0.4 π mm mrad into the RFQ
~ 85% RFQ transmission; ~ 20% emittance growth

MEBT Layout


RFQ
LINAC
PMQ
QUAD TRIPLET
CURRENT TRANSFORMER
BUNCHER
H & V STEERING
FAST CHOPPER
H & V STEERING
QUAD TRIPLET
BEAM STOP
SPIN PRECESSOR SOLENOID
BUNCHER
EMITTANCE & TRANSFORMER
QUAD TRIPLET
BUNCHER
CURRENT TRANSFORMER
QUAD TRIPLET
EMITTANCE & BEAM STOP

750 keV MEBT



Linac Performance

Location	**Current** (mA)	**RMS Emittance** (π mm mrad)
RFQ input	80	0.375
RFQ output	65	
Linac input	56	0.52
Linac output	39	1.92

Considerations for higher duty factors

1983: This source ran at 150 V x 150 A x 5 Hz x 600 μs = 68 W

With the present power efficiency, this would scale to 100 mA at 4.5 % duty factor.

The source is presently uncooled. Simple cooling of the source flange should be easy to add.

For lower beam currents, one could either

a. reduce the arc power, allowing even higher duty factors, or

b. reduce the extraction aperture, resulting in a smaller emittance and reduced gas flow at this duty factor

However, issues to be explored for higher duty factor:

increased gas flow → increased gas stripping

increased erosion of source parts, and heating of the extractor

Conclusions

•The magnetron is very reliable, and easily produces high current (100 mA). There is a lot of operational experience, across several accelerator labs.

•Cesium has not been a problem

•It should be possible to operate at higher duty factors than the 0.5% presently used (perhaps 5%).

•Emittance is higher than several other type H- sources.

•Source noise / current fluctuations are higher than several other type sources. This may or may not be a problem.